

PROGRESS REPORT

PR 91570-510-3

For the Period of September 1, 1963 through September 30, 1963

DEVELOPMENT OF A HYDROGEN-OXYGEN SPACE POWER SUPPLY SYSTEM

NASA Contract NAS 3-2787

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INTRODUCTION

This report is issued to comply with the requirements of NASA Contract, NAS 3-2787, and to report the work accomplished during the period September 1 through September 30, 1963. The objectives of this program are to conduct an engineering study, fabrication, and test work culminating in the design of an auxiliary electric power generation unit.

This Contract, NAS 3-2787, is a continuation of NASA Contract NAS 3-2550.

PROGRAM SCHEDULE

The program schedule is shown in Fig. 1. Development work on the prototype engine and compressor has been rescheduled to reflect the current status of the program.

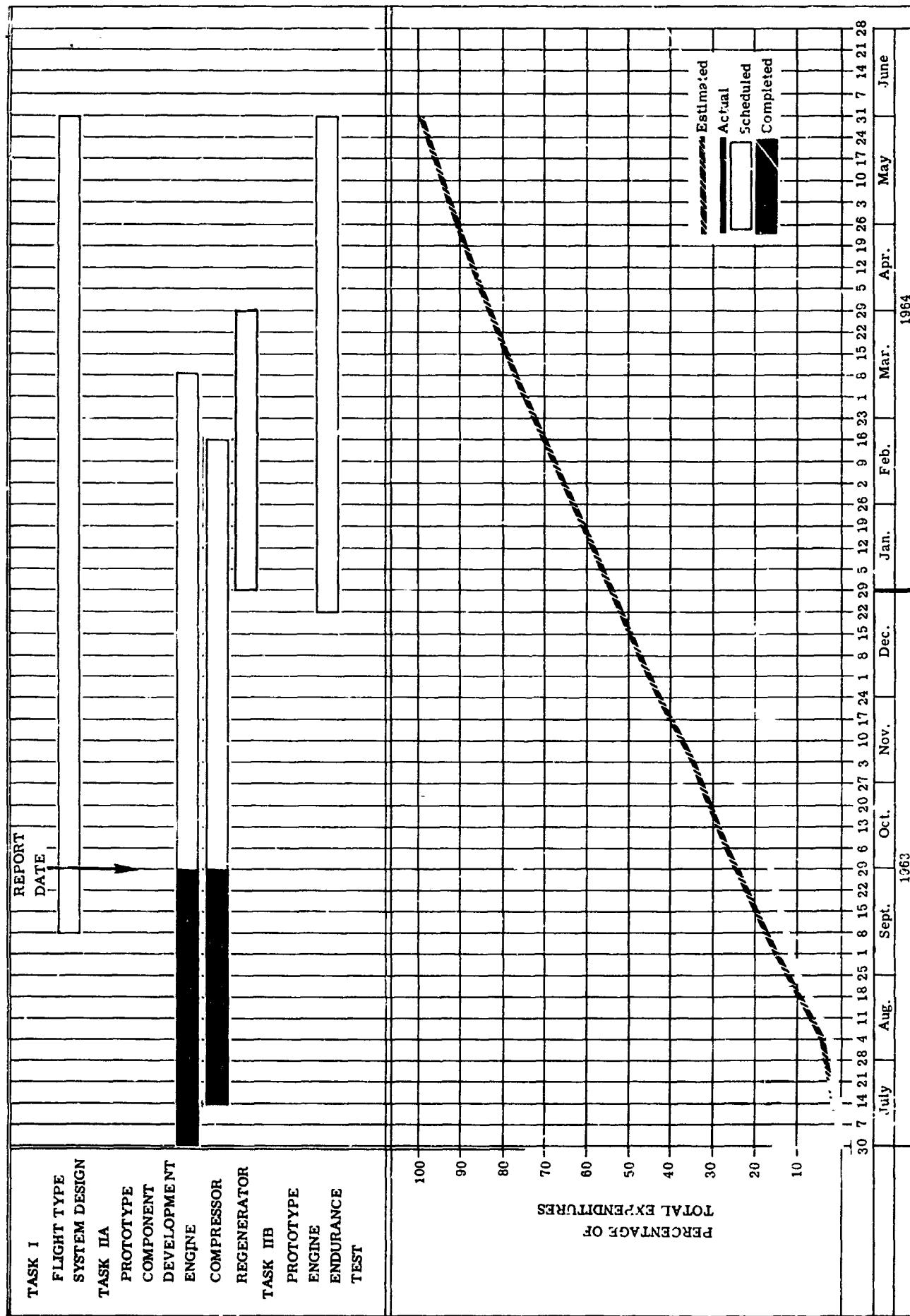
FLIGHT TYPE POWER SYSTEM DESIGN

No work was scheduled during this reporting period on the flight type power system design. Flight system design work has been postponed as a result of technical direction from the NASA Technical Program Manager.

RELIABILITY AND QUALITY ASSURANCE

The Reliability and Quality Assurance Program Plan has been completed, and a reproducible copy will be submitted to NASA during the week ending 14 October 1963. Detailed amplifications of specific procedures will be submitted to NASA as the program develops.

NASA CONTRACT NAS 3-2787
PROGRAM SCHEDULE AND PROGRESS CHART



PROTOTYPE COMPONENT DEVELOPMENT

Engine

Design and Fabrication

The following design and fabrication was accomplished during this reporting period.

1. Detail drawings of the redesigned hydrogen valve assembly (shown in Fig. 2 of PR-91570-510-2) have been prepared, checked, and released for fabrication.
2. An interim hydrogen valve spring design has been released for fabrication. This spring will allow the use of higher engine peak combustion pressures with the old hydrogen valve assembly, while parts are being fabricated for the redesigned valve.
3. A design study to revise the combustion chamber shape for controlling gas turbulence, to improve combustion efficiency, has been completed.

Detail drawings have been prepared, checked, and released for fabrication. The piston assembly will be reworked to the configuration shown in Fig. 2, and will be used with the redesigned piston dome shown in Fig. 3. This redesign lowers the top of the piston with respect to the hydrogen and oxygen inlet ports when the piston is at TDC, so that the edges of the redesigned cylinder head will extend below the

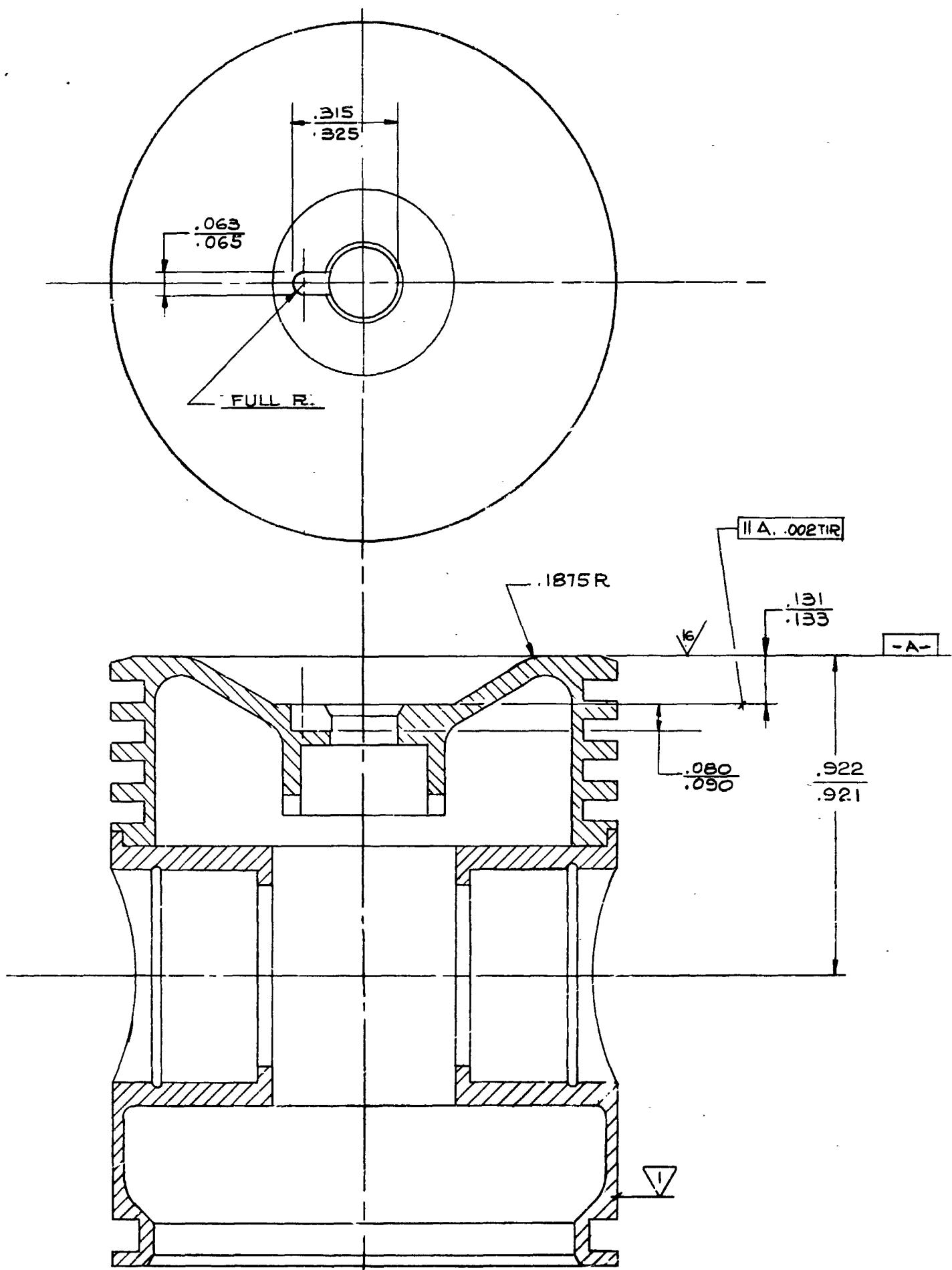


Fig. 2 - Redesigned Piston Assembly

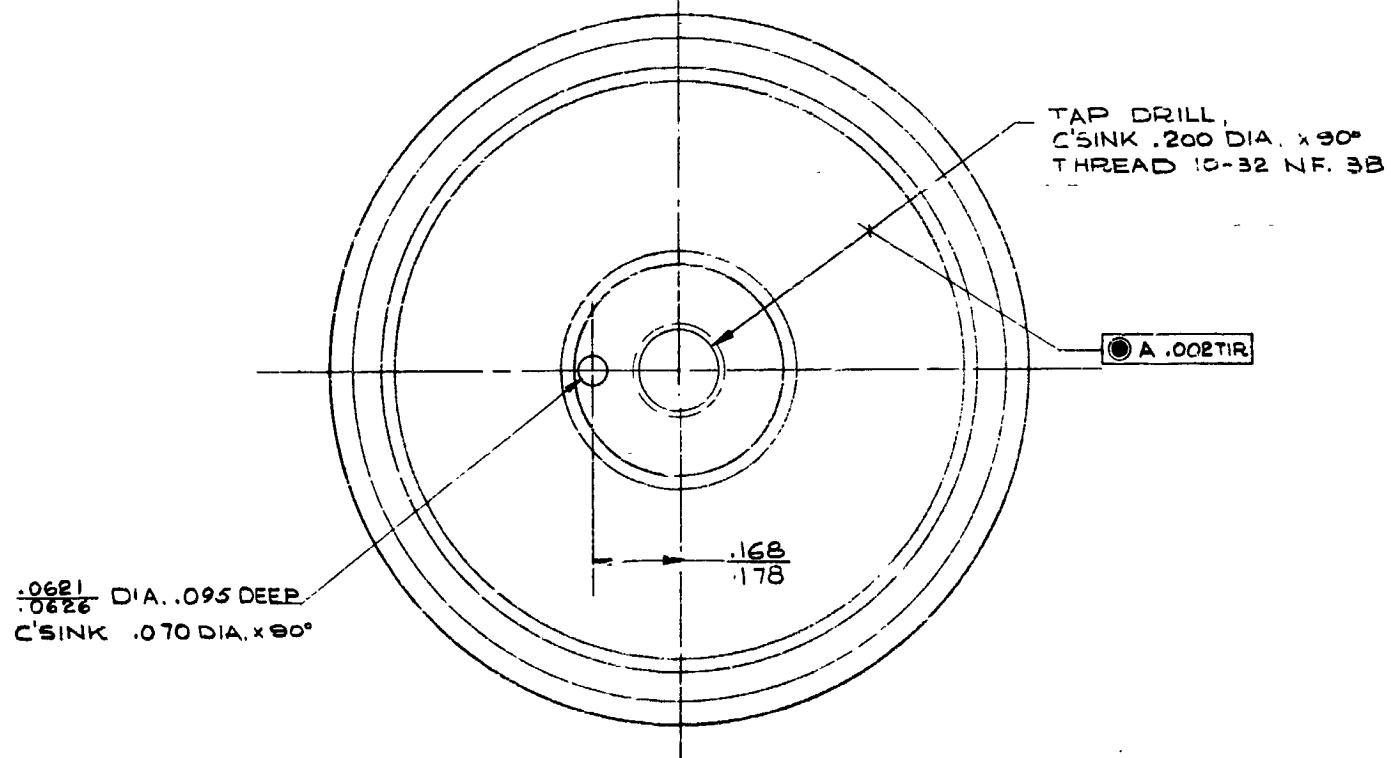
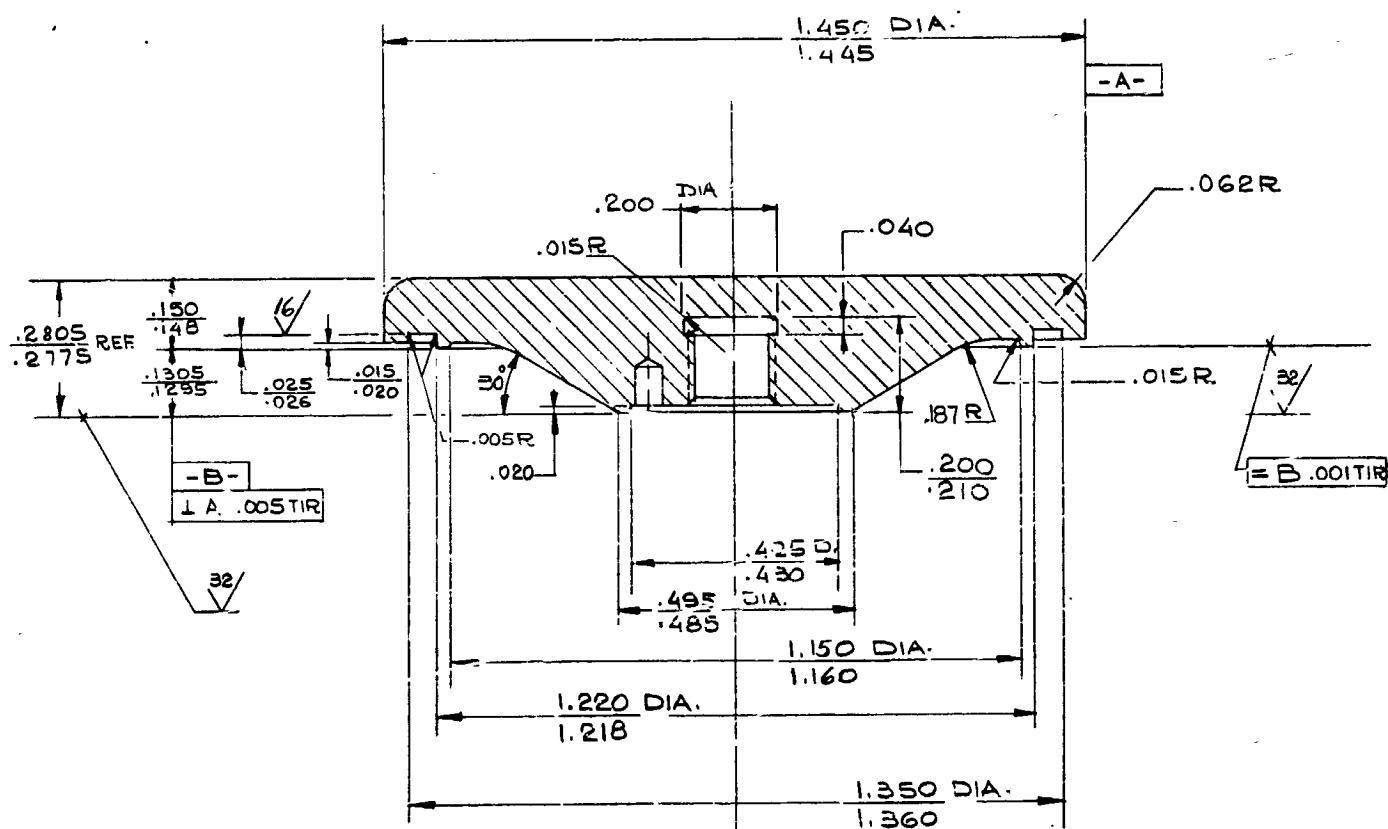


Fig. 3 - Redesigned Piston Dome

hydrogen inlet port provide means of swirling the incoming hydrogen. The redesigned head inserts shown in Figs. 4 and 5 were designed for the second engine assembly to allow for clearance volumes of 4.4% and 12% respectively. Fabrication of these parts is scheduled for completion by October 11, 1963.

4. Detail drawings of a cooled cylinder head shown in Fig. 6, have been detailed, checked, and released for fabrication. The cooled cylinder head will be machined to the combustion chamber shape of a non-cooled head, and a performance comparison of the two will be made.
5. Interim oxygen injector poppets and matched integrated seats-guides of the redesigned configuration have been fabricated. The oxygen injector poppets were not flame plated. Linde LC1B55 flame plate will be applied to the poppet guide surface on later units. One set is now in use in an injector assembled with the old flex pivot bearing design. These interim parts may also be used with the new journal bearing design.
6. The layout drawing of the oxygen injector drive linkage (described on Page 6 of PR 91570-510-2) is near completion, and detailing of parts will start during the week ending October 12, 1963. This new drive linkage will reduce the effects of thermal expansion.

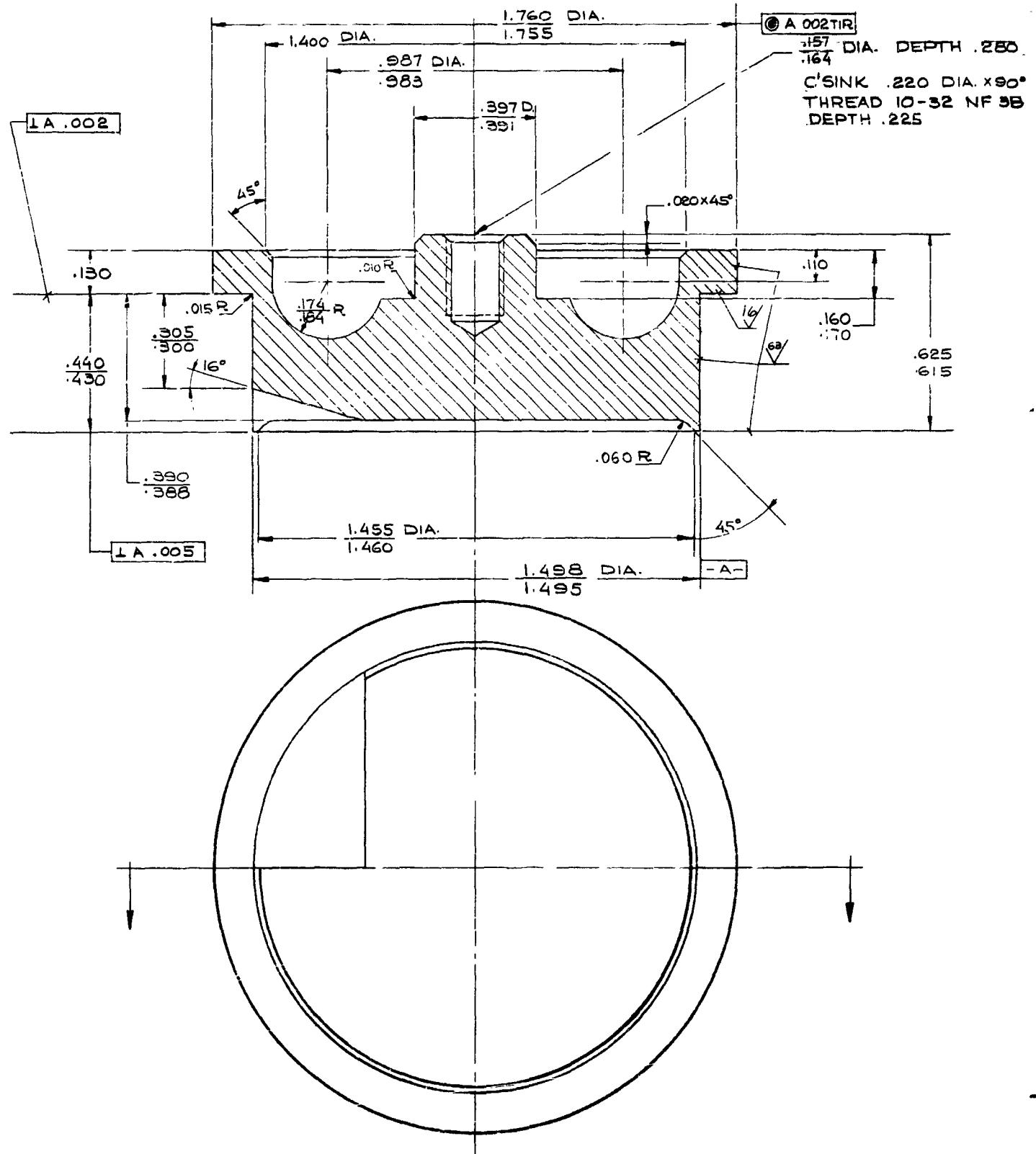


Fig. 4 - Redesigned Head Inserts

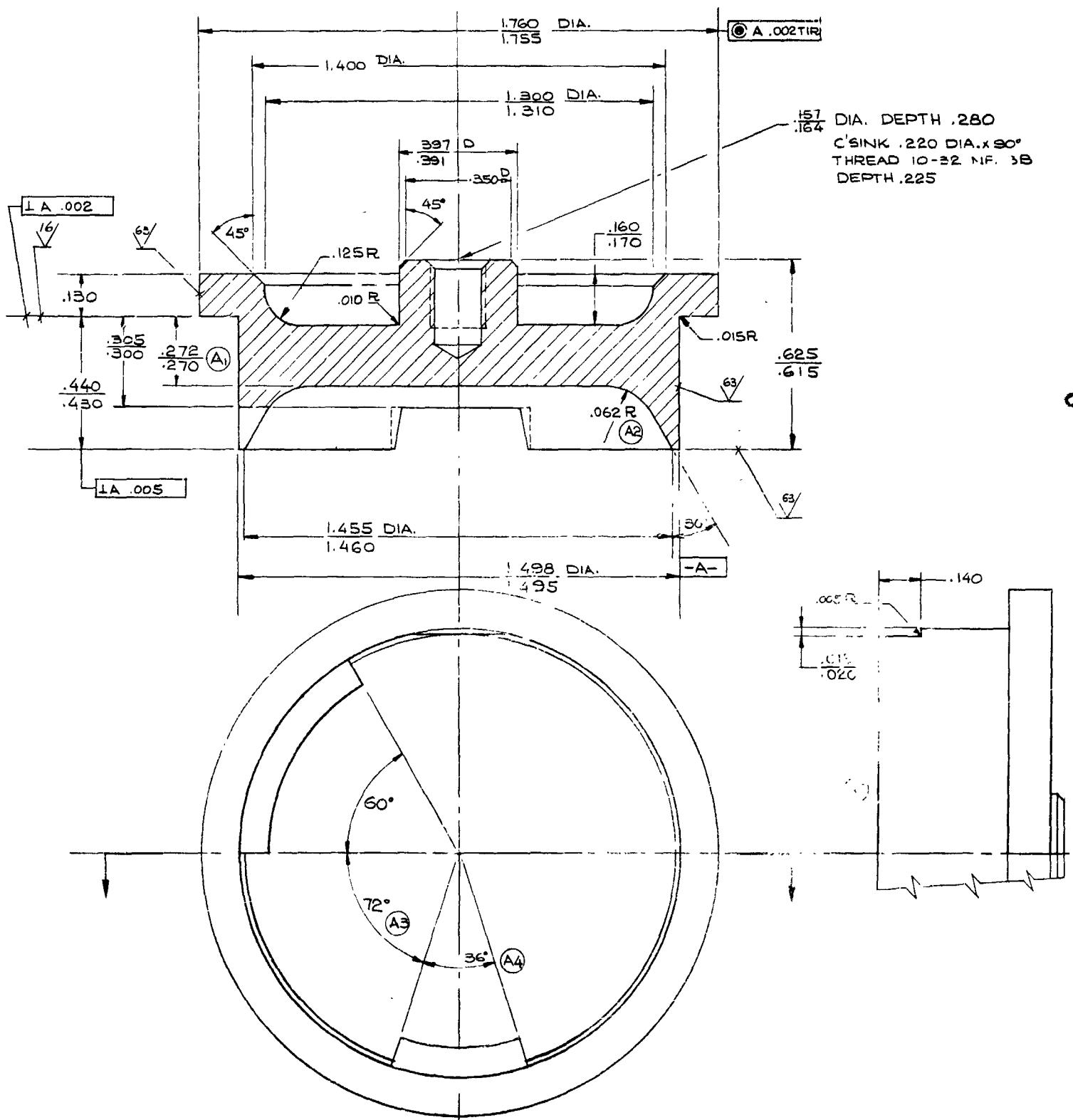


Fig. 5 - Redesigned Head Inserts

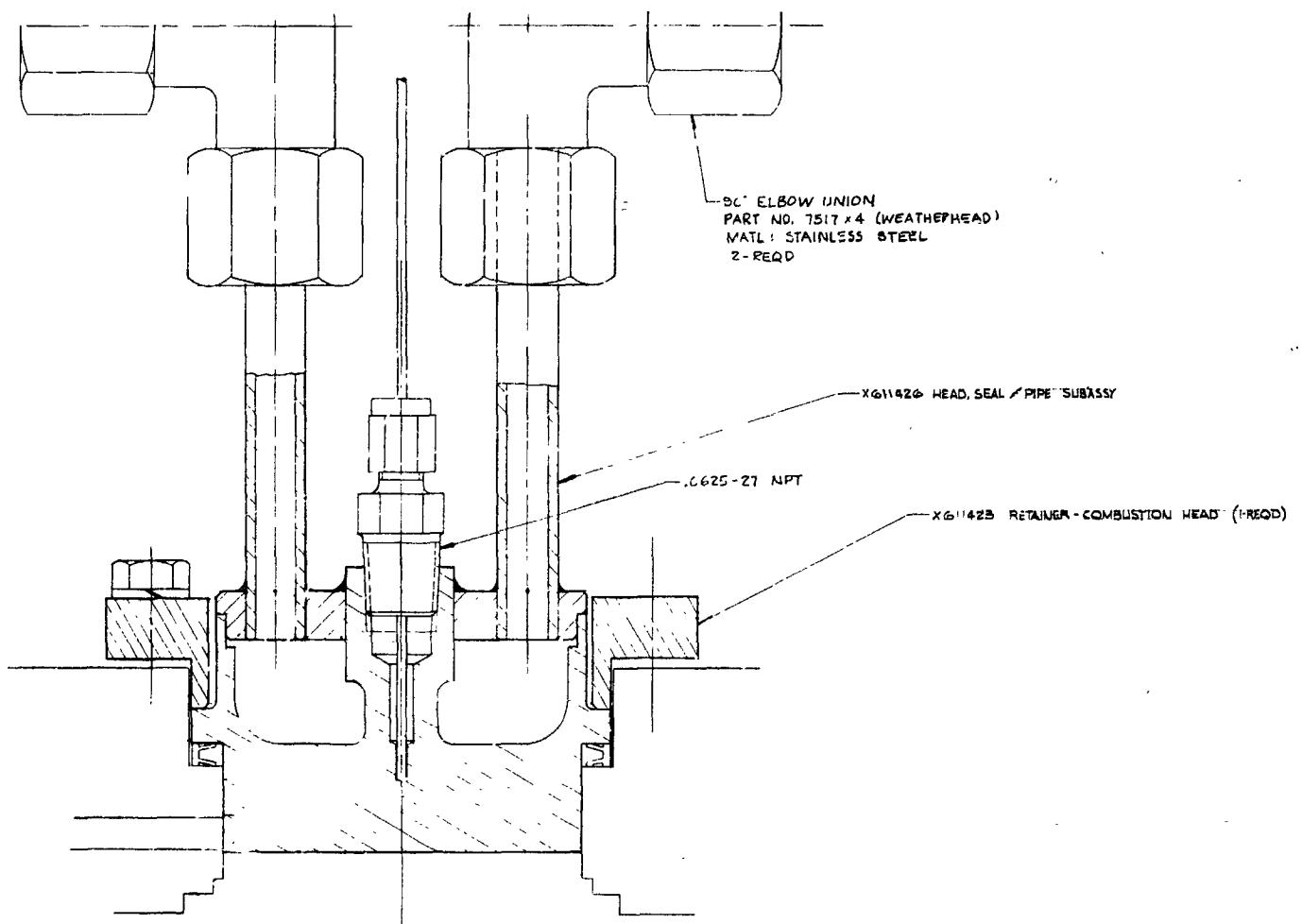


Fig. 6 - Cooled Cylinder Head Design

Assembly Build-Up

Parts to be installed in the second engine assembly have been inspected to determine the actual dimensional relationship of exhaust, hydrogen and oxygen ports, and the combustion chamber dome with respect to the piston. A procedure for the serialization of parts and maintaining of engine records has been put into effect.

Performance Tests

Expansion and motoring tests have been completed and the engine has been operated as an internal combustion engine for one 41-minute run. Checkout of the balanced diaphragm cylinder pressure measurement set-up is nearly complete. Operating time on this engine as of September 30 is given below.

	<u>Engine</u>	<u>Injector</u>
Cold Gas Expansion Tests	8.9 hrs.	-
Motoring on Cold Gas or Hydraulic Power	5.4 hrs.	5.4 hrs.
Hot Tests	41 min.	41 min.

Friction Tests

FMEP vs. engine rpm is given in Fig. 7. It can be seen that friction is excessive at over 3000 rpm. Due to the considerable hysteresis in load cell readings this information is considered preliminary, and must be verified in future motoring tests. However, there is other evidence of high engine friction such as the performance of the engine as an expander when operating at low MEP levels.

FRICITION MEAN EFFECTIVE PRESSURE

V.T.

ENGINE RPM

NOTES:

1. CYLINDER HEAD REMOVED
2. OXYGEN INJECTOR VALVE THEM
NOT OPERATING
3. AIR TEMPERATURE 130° F (34°C)
4. TWO COMPRESSION RINGS
5. BLOWNIN O-5000 LITER/SEC

50

40

30

20

10

F.M.E.P. - psi

0 0 1000 2000 3000 4000 5000 6000

SPEED - RPM

Fig. 7

9/23/63

Expansion Tests

Expansion test data is given in Figs. 8 through 10 in the form of $BSPC\ RT$ versus $BMEP/P_H$. These quantities, which have been defined in previous reports, and in the final report for NASA Contract NAS 3-2550, are general performance parameters independent of mixture ratio or temperature. Heated hydrogen was admitted through the hydrogen inlet valves at temperatures between 115°F and 200°F . The oxygen injector valve was replaced by a plugged dummy valve body.

Fig. 8 shows the results for very low admission, 4% of the total stroke, with the results correlated as a function of pressure. In Fig. 9, the admission is higher (14%) and the correlation is smoother, with a definite minimum for each pressure. The minimum points are lower, as higher inlet pressures are reached because of the greater stored pressure energy available, and because the relative effects of friction ($FMEP/BMEP$) become less.

Due to the high rate of hydrogen consumption, only a few data points were taken with 24% admission and 450 psig hydrogen inlet pressure, these are shown in Fig. 10.

Pressure time traces obtained by the Kistler pressure transducer were photographed on the oscilloscope for each run. Four of these traces were plotted as pressure volume diagrams and are shown in Figs. 11 through 20, first on a linear scale and then as log-log plots.

A high speed, low admission, high pressure run is shown in Figs. 11 and 12, (5000 rpm, 4%, 750 psi). The area of the enclosed curve yields an average pressure (IMEP) of 41 psi. When

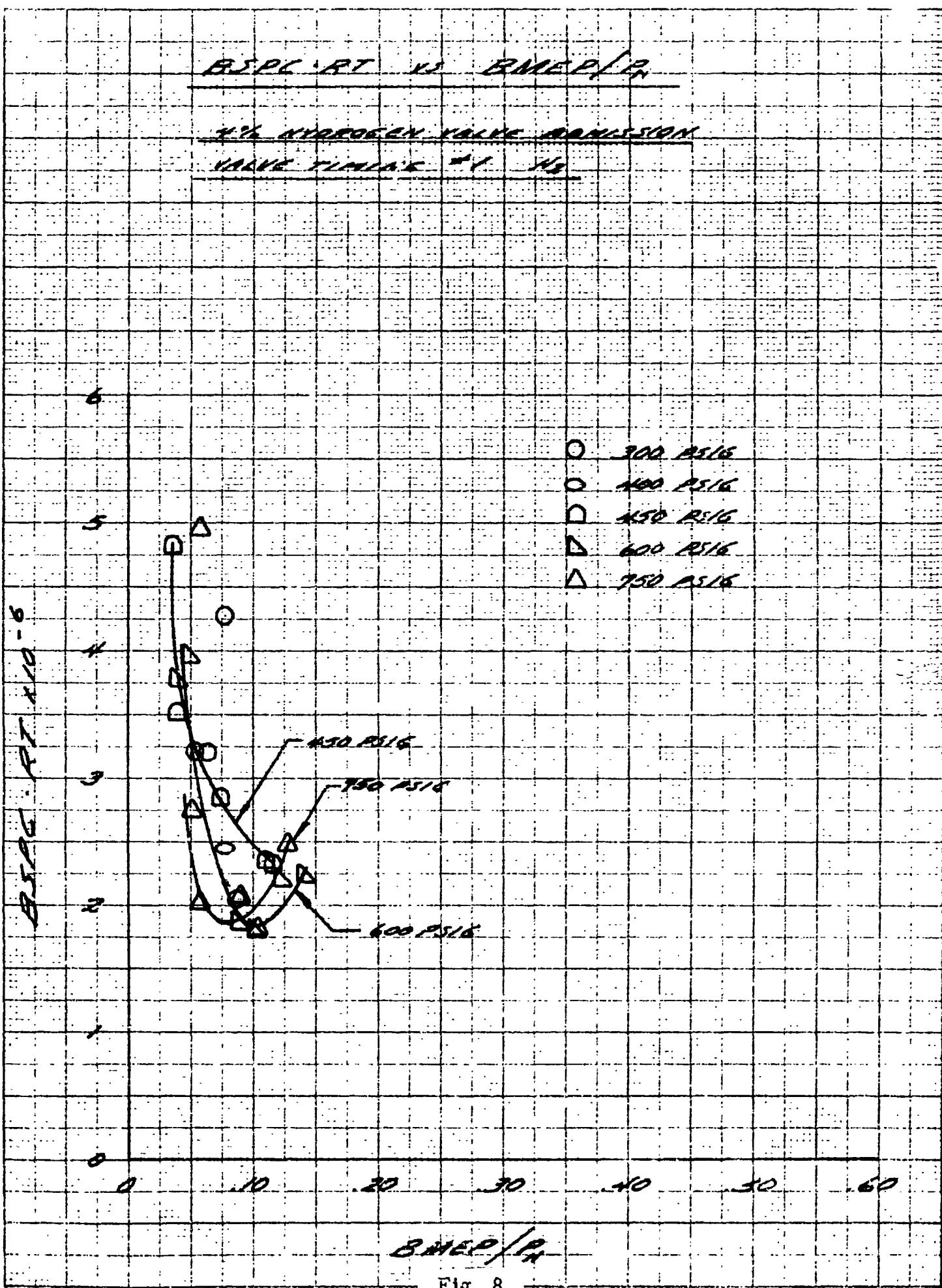


Fig. 8

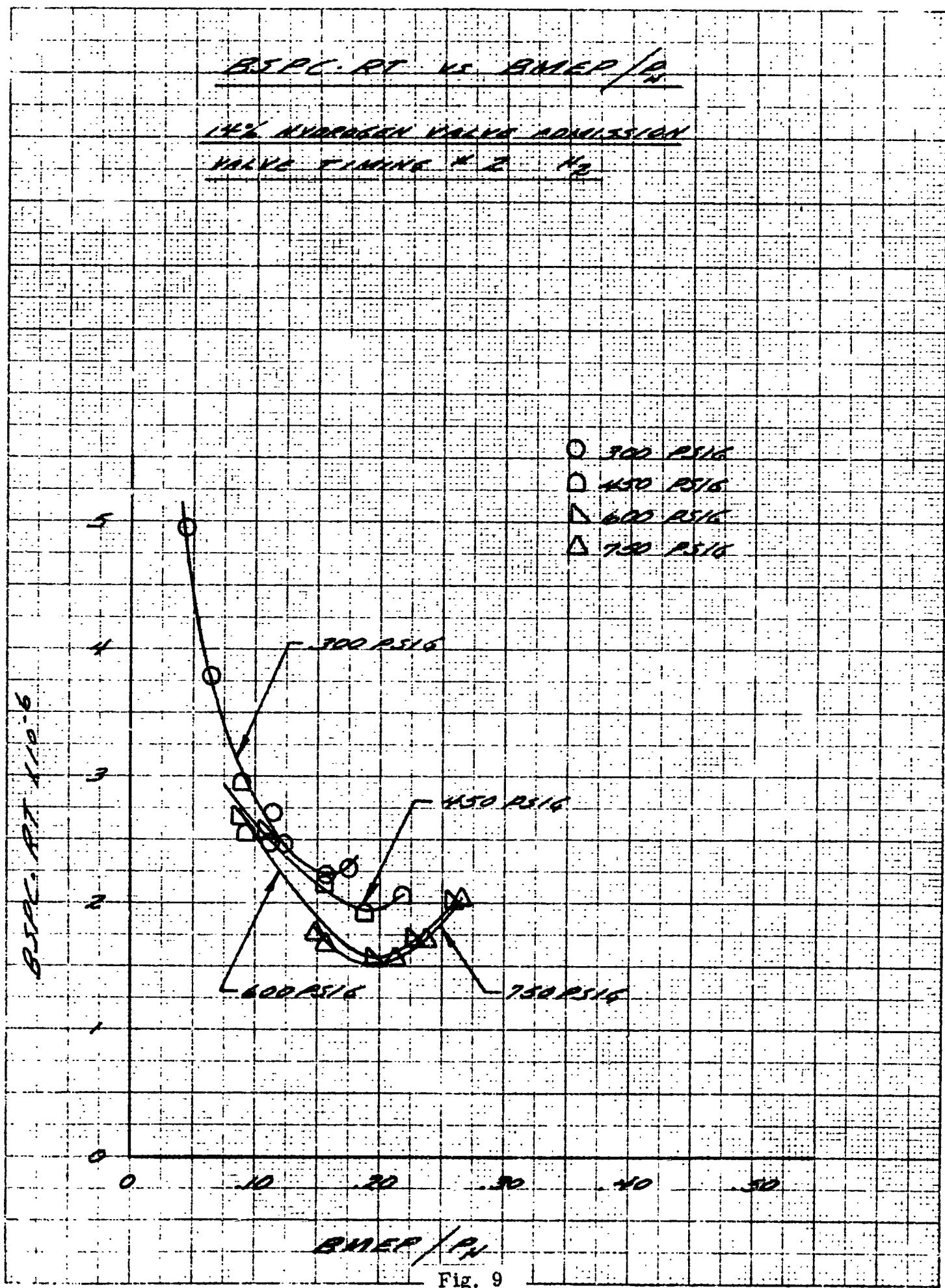


Fig. 9

95% RT vs BMEP/PA

24% hydrogen valve admission
VALVE TIMING + 3 deg

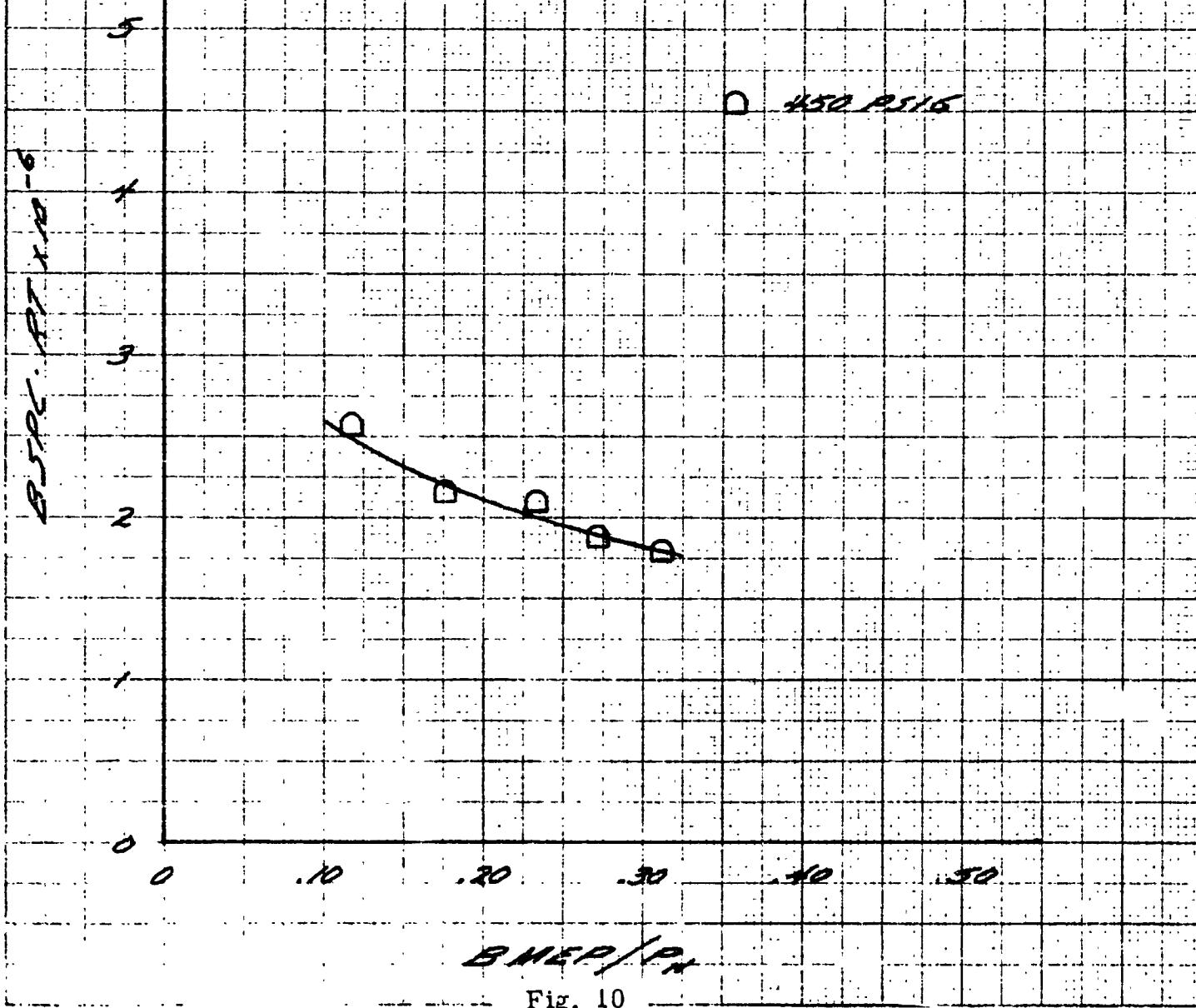


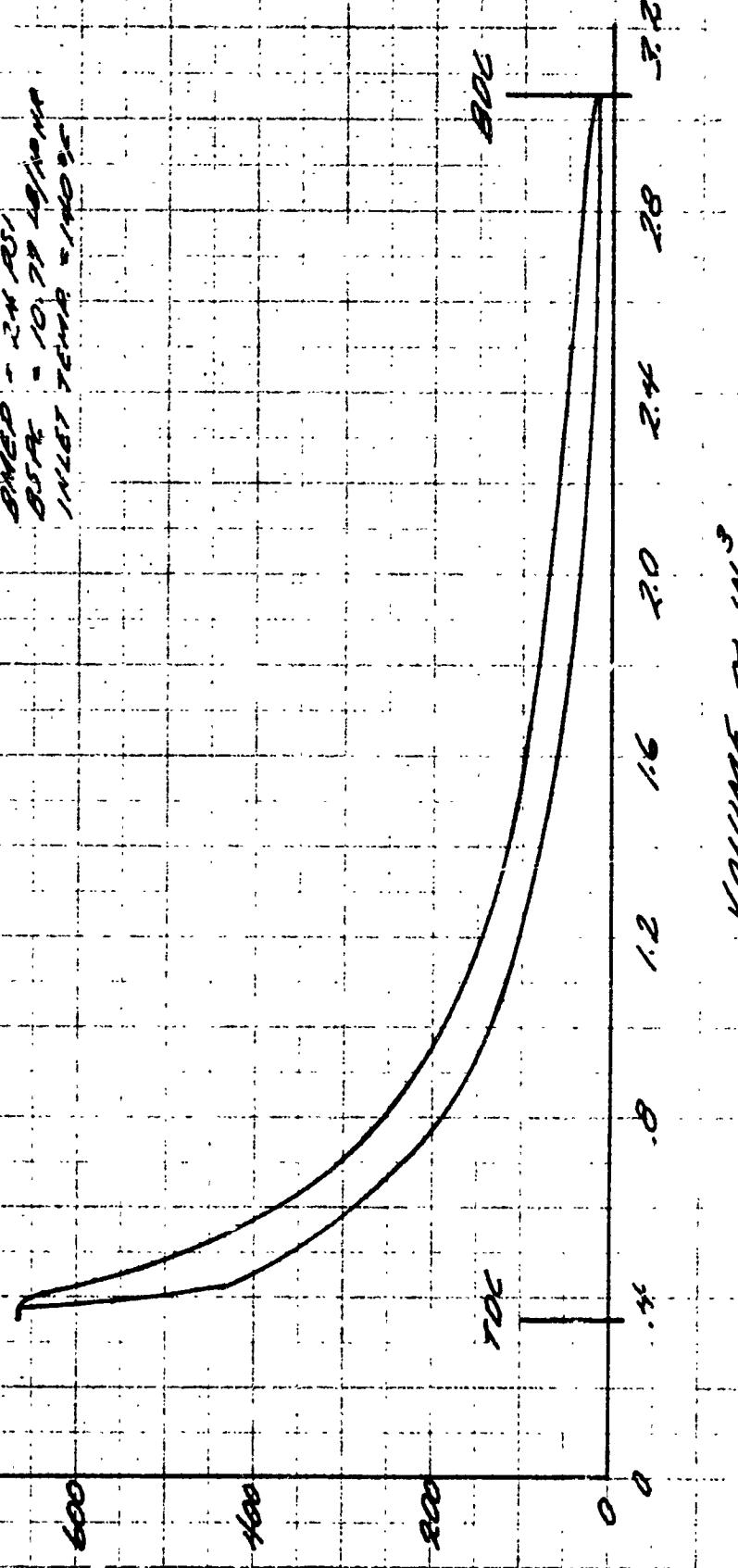
Fig. 10

40405-51-074557 ENGINES
CHARACTERISTIC CARD
 (cold air passes)

INTER COOLER : 20000
 TACCO = 5000 ft
 13% CONDENSATE RECOVERY
 TEST DATE 8/20/63 (NO. 43)

$$P_{0.9} = .8940$$

$$\begin{aligned} \text{MFD} &= 44.25 \\ \text{SFC} &= 24.25 \\ \text{SFC} &= 10.75 \text{ lb/m} \\ \text{SFC} &= 10.25 \end{aligned}$$



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Fig. 11

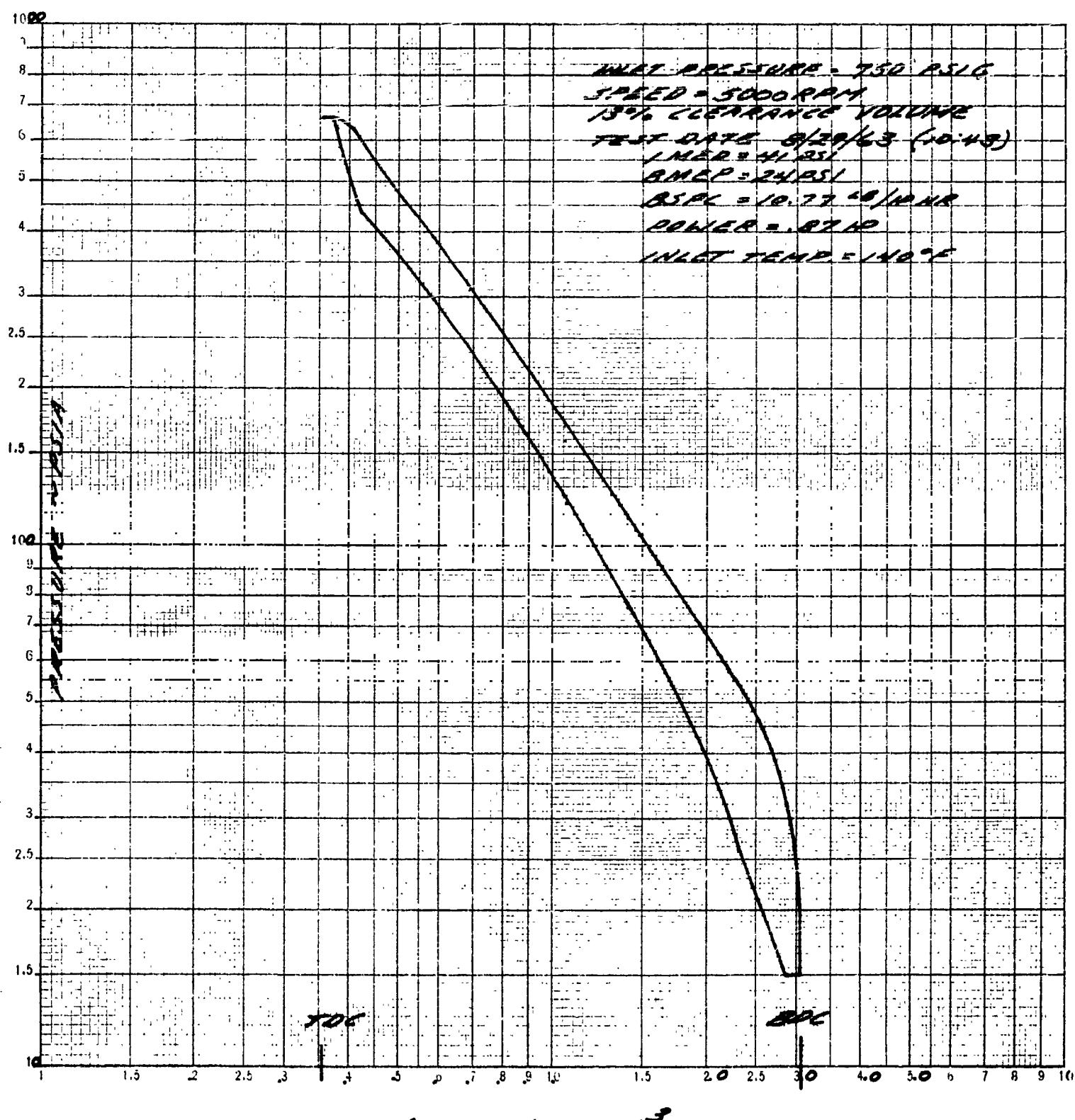


Fig. 12

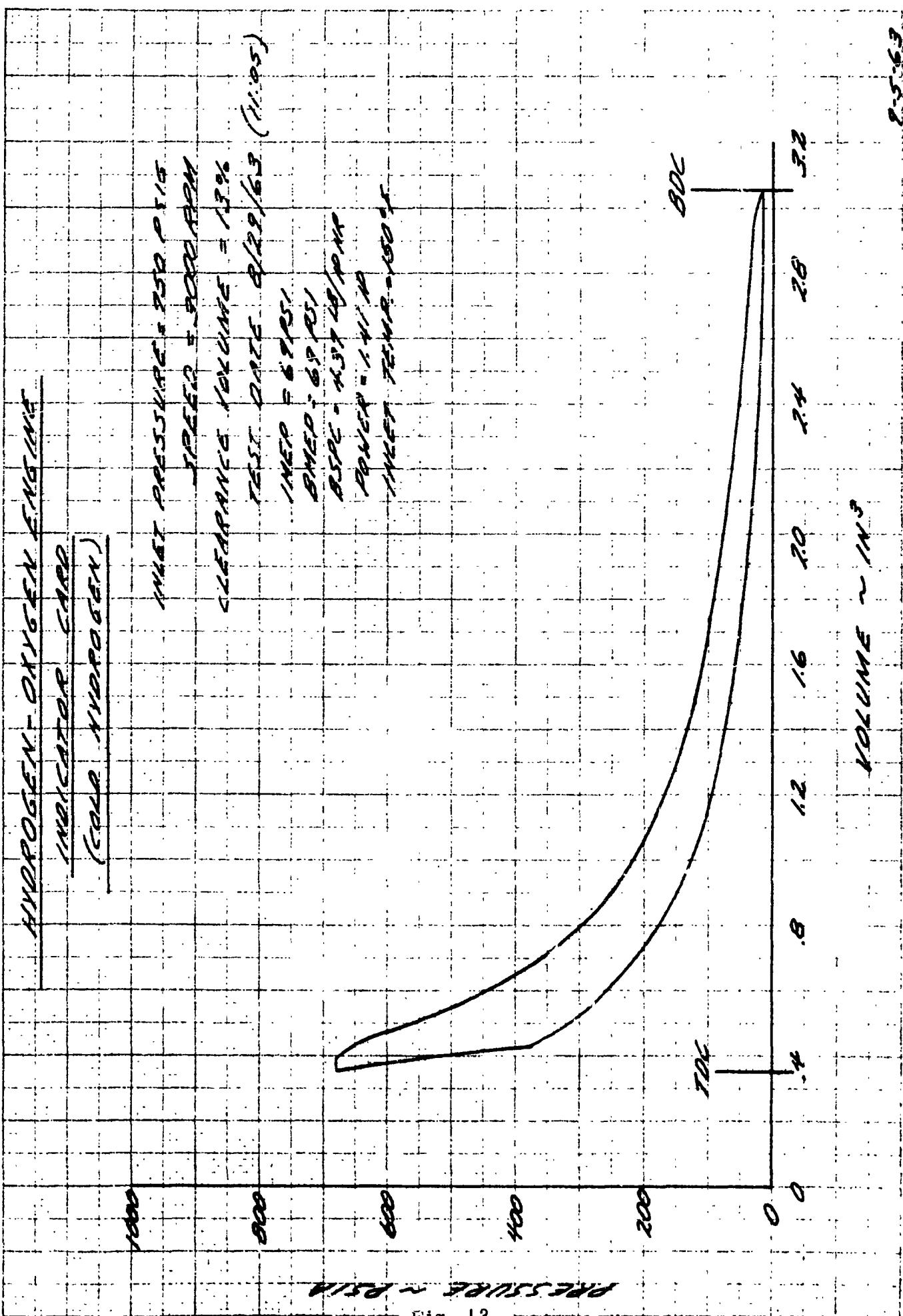
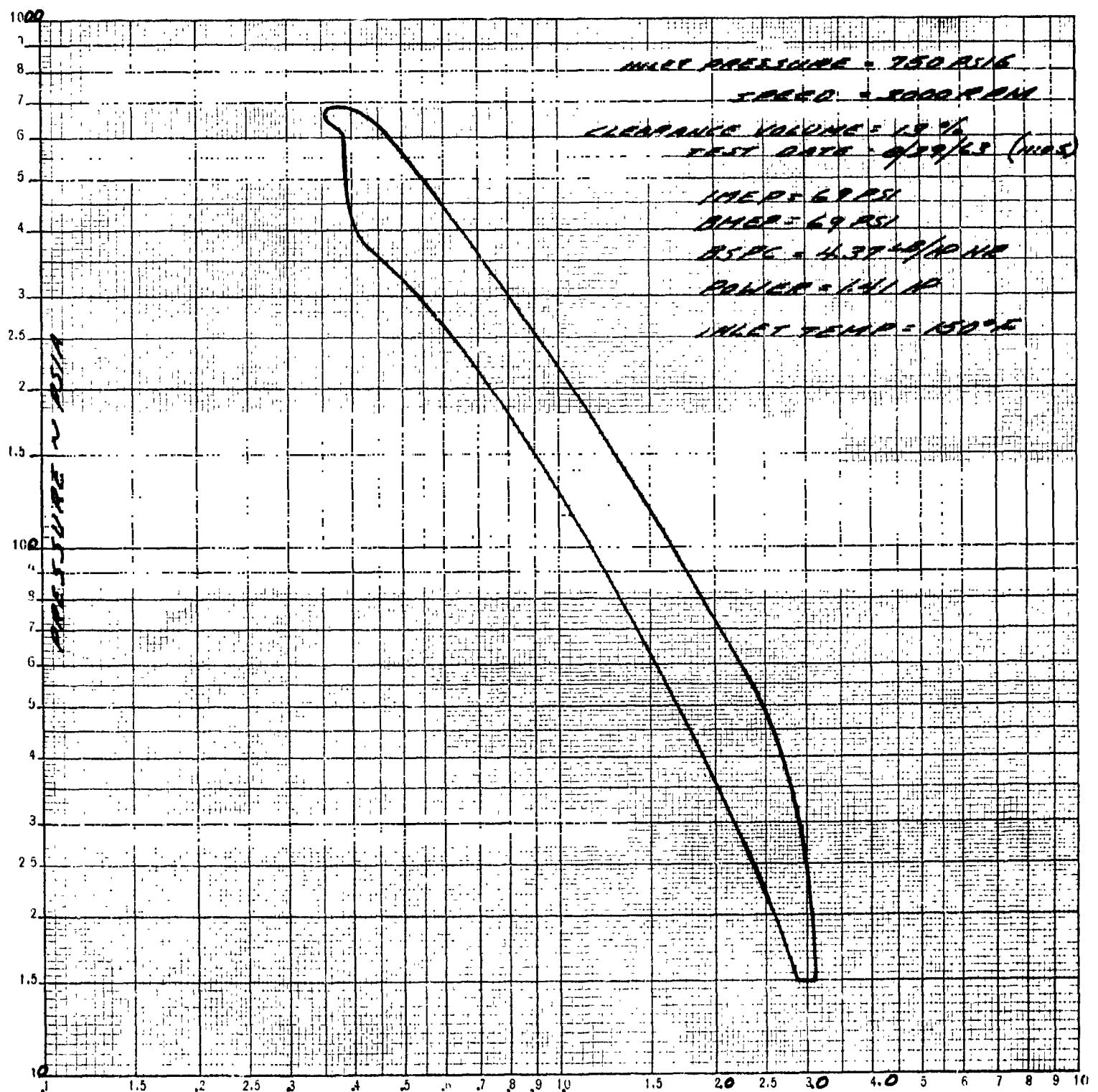


Fig. 13



VOLUME ~ IN³

Fig. 14

9-4-65

Proposed - Given and the
known case
(case treated)

$$\text{Initial } \text{P}_0 = 2000 \text{ psig}$$

13% CHPA heat rejection

1000000 ft² total area of surfaces (treated)

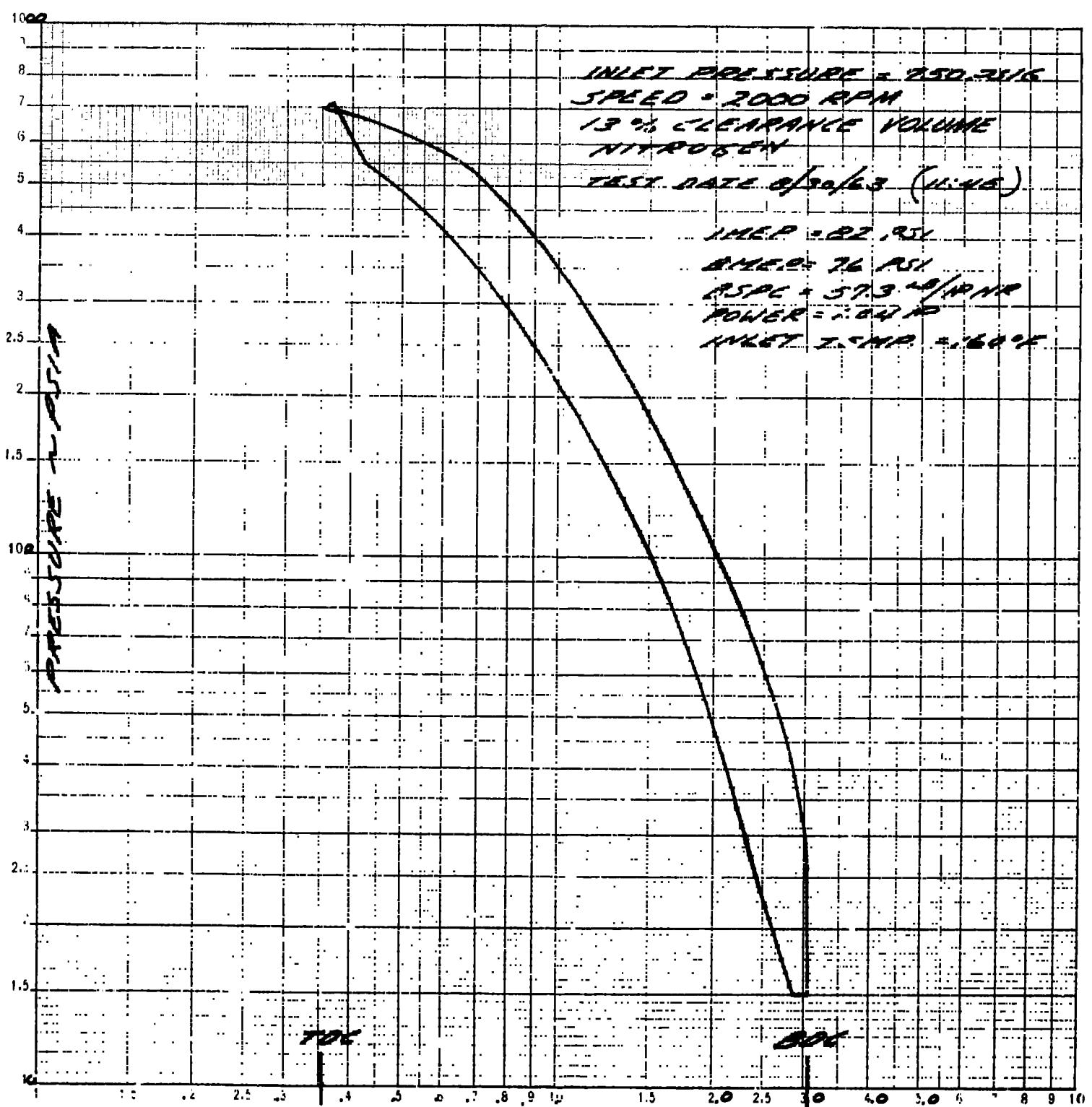
$$V_{000} = 0.00001$$

$$\frac{dV}{dt} = 10^{-5} \text{ m}^3/\text{s}$$
$$\frac{dV}{dt} = 10^{-5} \text{ m}^3/\text{s}$$

Heat removal = 1000000

2000 1000 500 250 125 63

Fig. 15



VOLUME IN³

Fig. 16

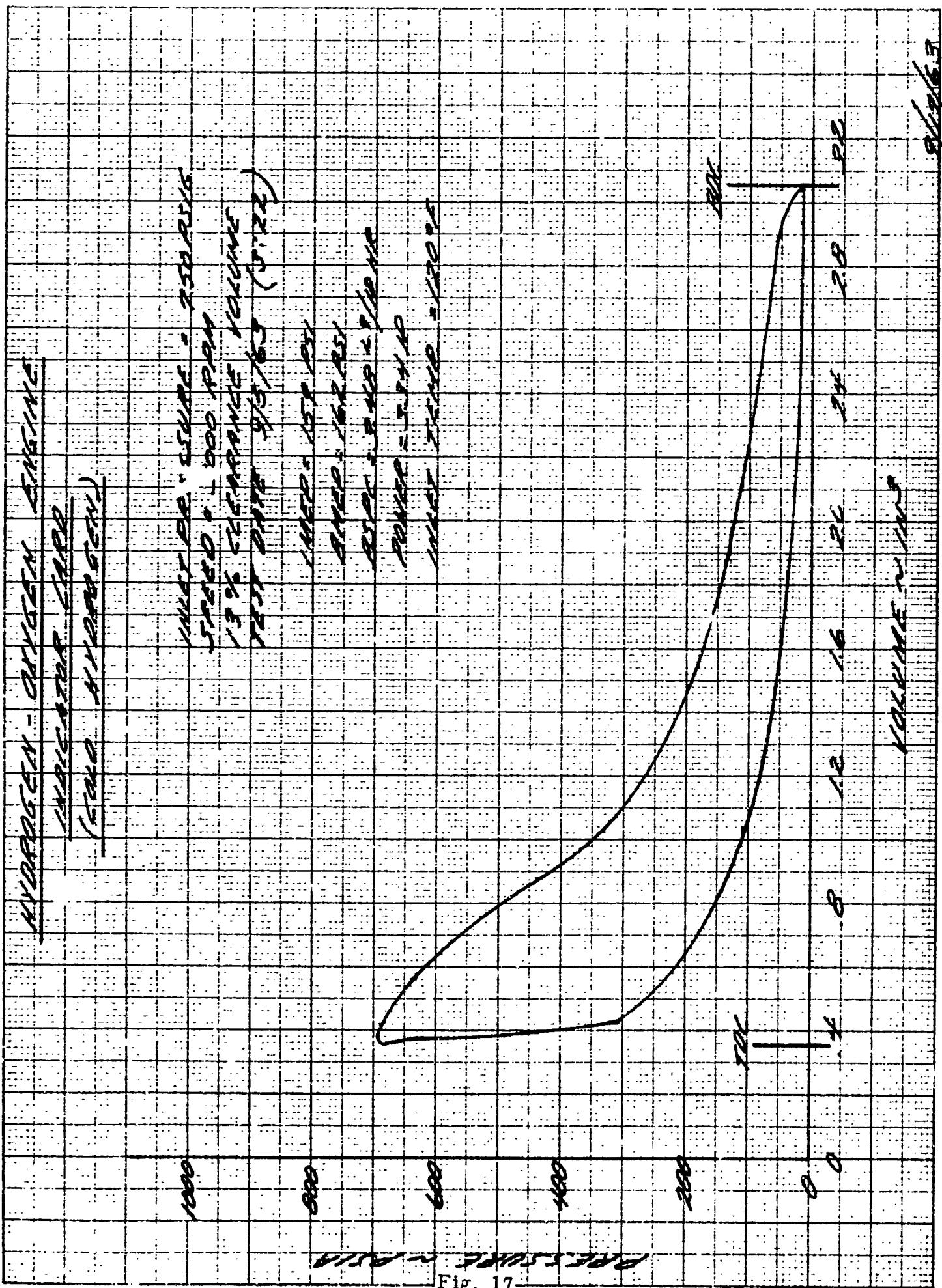
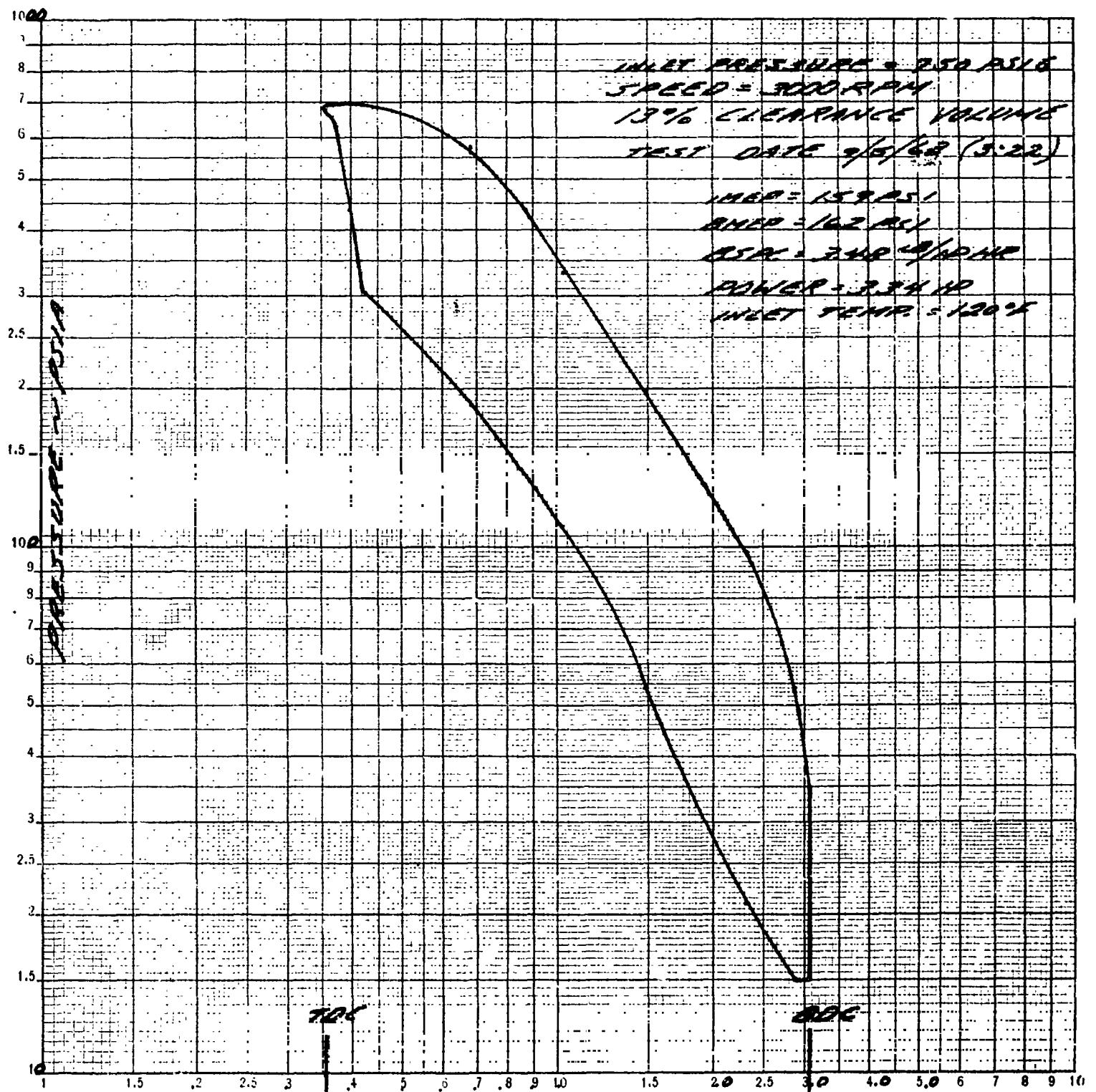


Fig. 17



VOLUME V/in^3
Fig. 18

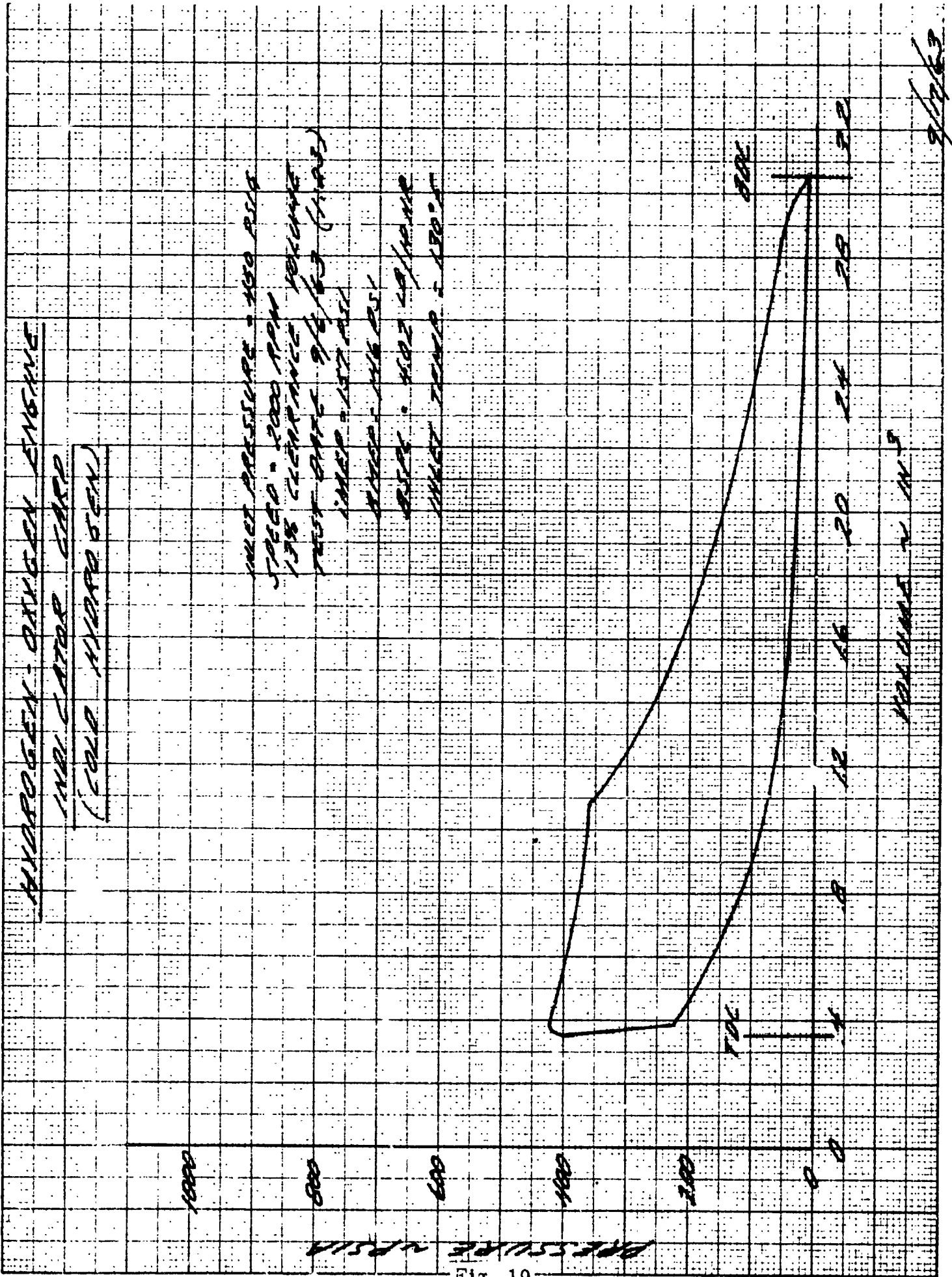
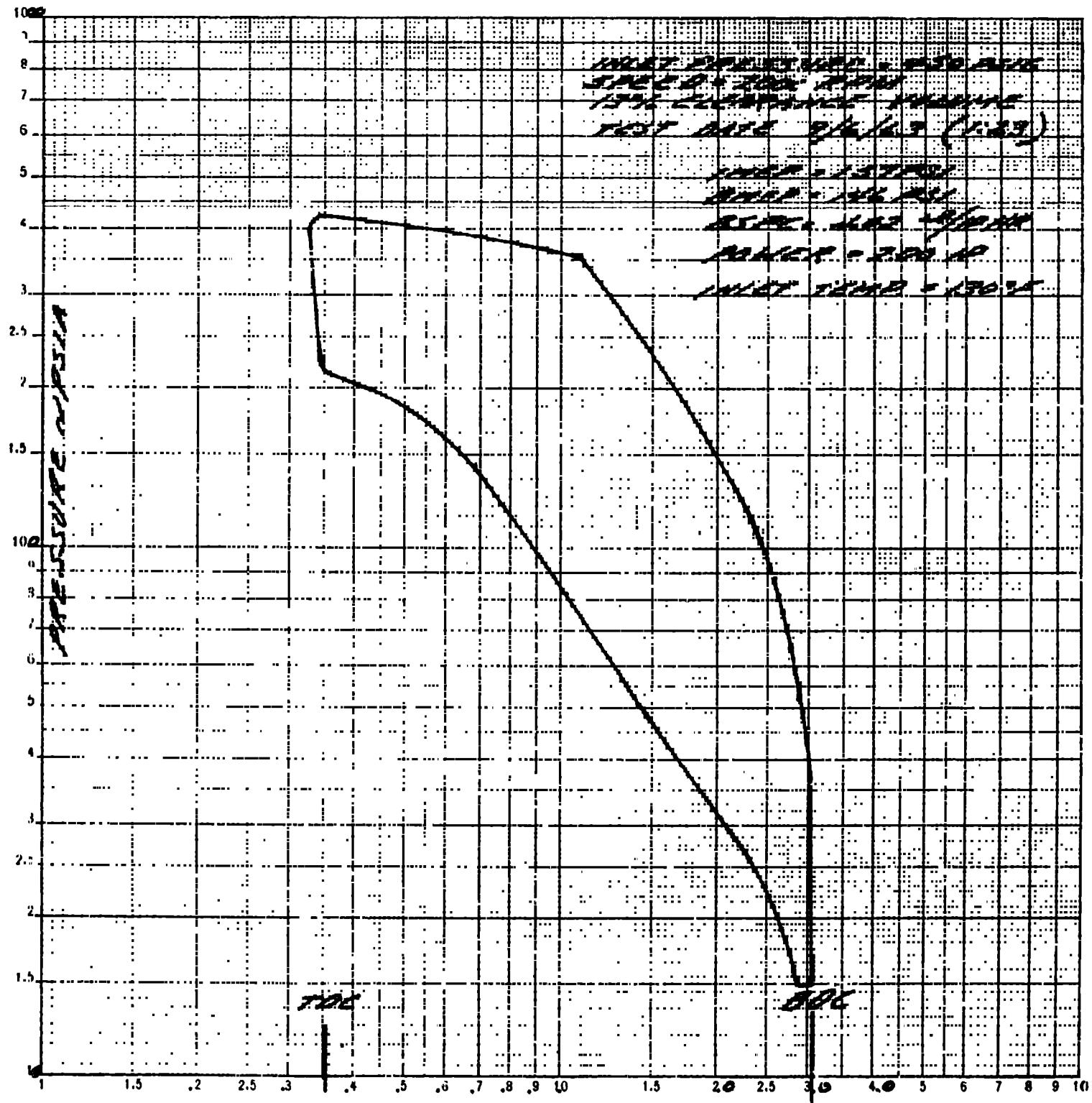


Fig. 19



VOLUME - IN³

Fig. 20

speed is dropped to 3000 rpm the IMEP becomes 69 psi as shown in Figs. 13 and 14. The engine was motored on nitrogen at 14% admission, 2000 rpm for the run shown in Figs. 15 and 16. The excessive throttling is the result of the very high piston Mach number (the equivalent engine speed on hydrogen would be 7500 rpm).

Motoring the engine on hydrogen at 14% admission, 750 psi, and 3000 rpm gave an IMEP of 159 psi. The indicator cards are shown in Figs. 17 and 18. These can be compared to Figs. 7 and 8, which are identical except for admission.

Figs. 19 and 20 show the high (24%) admission at 2000 rpm, 450 psi hydrogen inlet pressure. If throttling were not present the pressure would remain at the inlet peak until expansion began.

The lowest BSPC RT of these runs is 1.5×10^6 ft. lb/hr-hp. The lowest BSPC RT achieved during internal combustion engine tests on the Phase I program (Contract NAS 3-2550) was 1.95×10^6 . This would represent an improvement of 23%, or a drop from 2.2 lb/hp-hr. to 1.7 lb/hp-hr., if the engine can be made to run this well as an internal combustion engine at its most favorable MEP.

Test Equipment

1. The Model KD850 Kinney Vacuum pump has been received, and a mounting slab has been poured.
2. Parts of the quartz cylinder head window have been released for fabrication. This assembly will be used to view and photograph the engine combustion process.

3. Parts for a piston inspection fixture are being fabricated. This fixture will be used to check for leakage of the piston dome seal.
4. Components for a high temperature, recirculating cylinder wall cooling system are being procured.
5. The concept of an oscilloscope readout, balanced pressure, engine indicator system has been demonstrated. A simplified schematic of the system is shown in Fig. 21. The system consists of:
 - a. A water cooled Photocon balanced diaphragm pressure switch.
 - b. A regulated nitrogen supply
 - c. A Bourns No. 304 pressure transducer
 - d. A 0-1000 psi pressure gage
 - e. A nitrogen bleed valve
 - f. A flywheel coated with magnetic tape which is magnetically marked at desired crank angles
 - g. A tape recorder head
 - h. A dual beam oscilloscope
 - i. A Polaroid camera
 - j. Necessary plumbing, fixtures, and electrical circuits

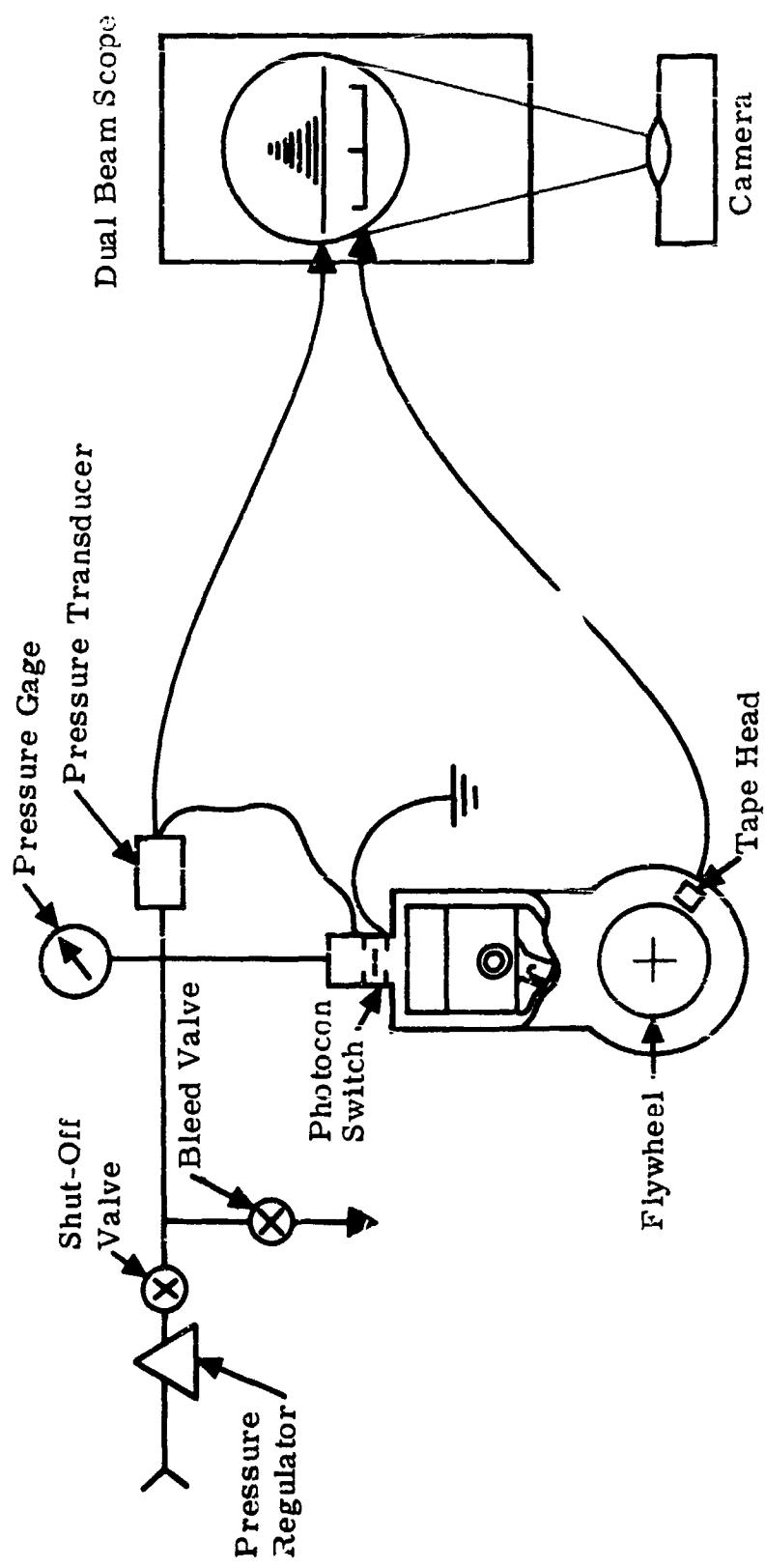


Fig. 21 - Engine Indicator System Schematic

A schematic of the electrical circuit for the Photocon switch and Bourns Pressure transducer is shown in Fig. 22.

The balance pressure side of the photocon switch is initially pressurized to a level above anticipated peak cylinder pressure. The pressure is bled off (with the engine running) while a time exposure photograph of the oscilloscope tube is taken. The decaying nitrogen pressure changes the crank angle at which the photocon switch opens and closes. This change is due to the changing pressure unbalance between the nitrogen pressure and cylinder pressure.

Since the Photocon switch is used to switch the electric output of the pressure transducer in the nitrogen line, the magnitude of the cylinder pressure as well as a crank angle at which the switch opened and closed is displayed on the scope and photograph. The other beam of the scope traces accurate crank angle position blips picked up by the tape recorder head from the magnetic tape mounted on the engine flywheel.

Fig. 23 is a photograph taken during the development of the system. Only TDC and BDC crank angle position marks were used. The engine was motored hydraulically with nitrogen entering the cylinder at low pressure during the test.

REGENERATOR

No work scheduled this reporting period.

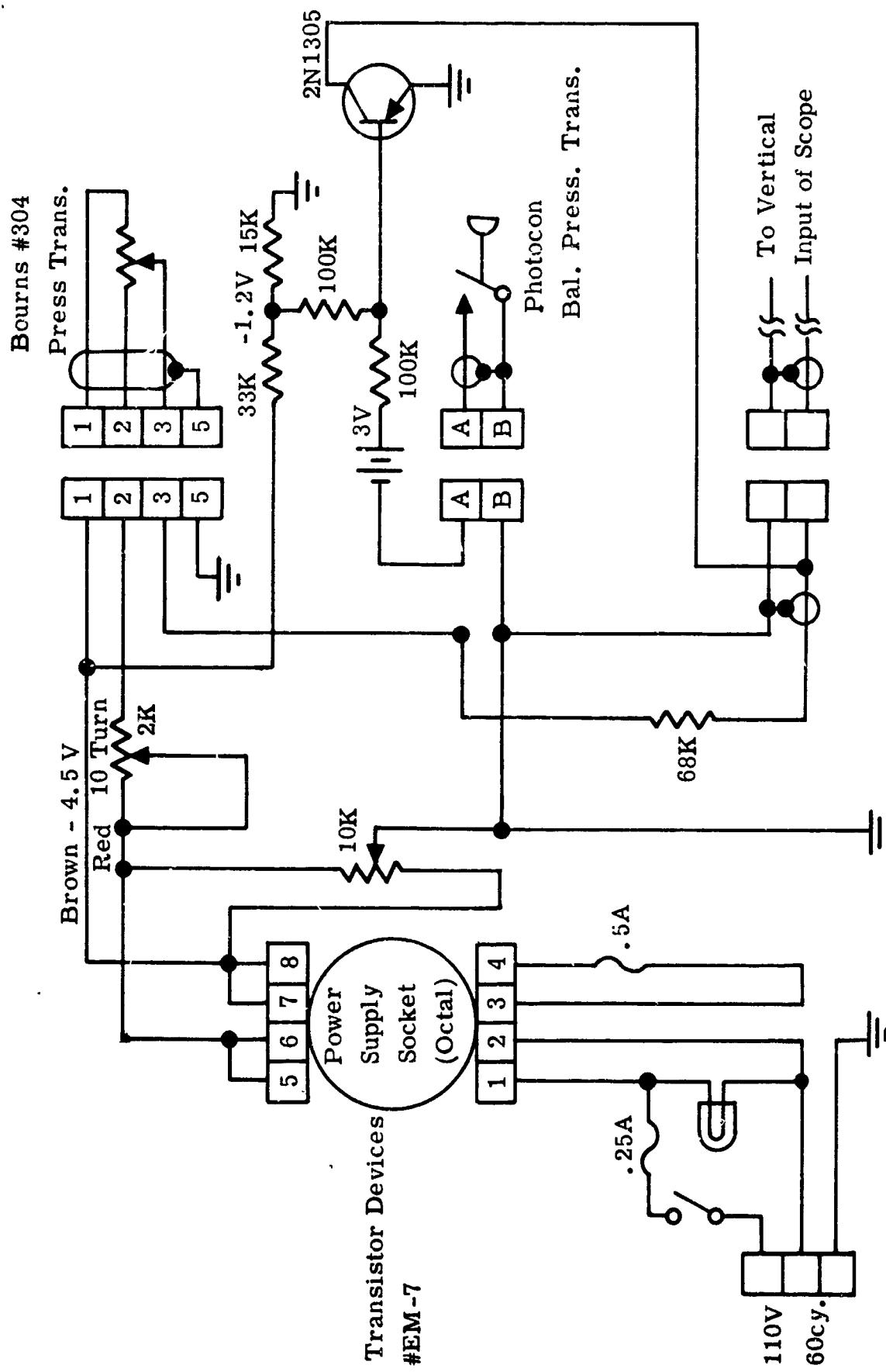
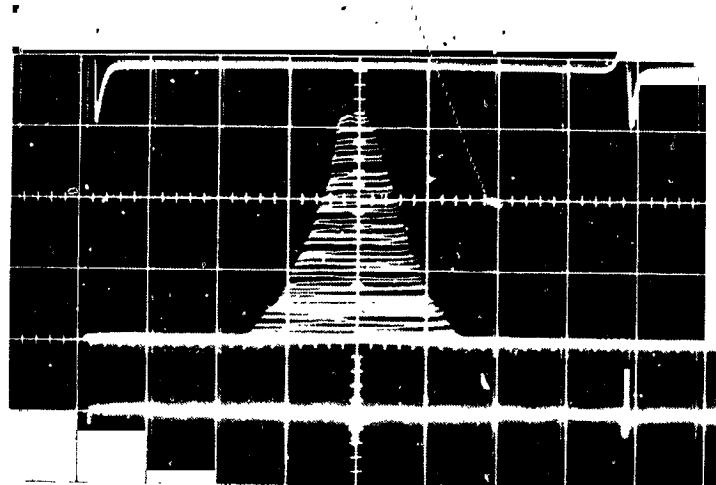


Fig. 22 - Schematic for Bourns Pressure Transducer and Photocon Switch



**Fig. 23 - Oscilloscope Trace, TDC and
BDC Crank Angle Position**

COMPRESSOR

1. A detail drawing for the new first stage cylinder head design has been released for fabrication.
2. Detail test plans are being prepared and test fixtures designed for the evaluation of compressor sub-assemblies prior to bench test of the complete assembly. A record system is being established for part and assembly identification and performance data.
3. The test stand is being refurbished and improved to obtain a more rigid mounting platform and to reduce vibration. The external drive mechanism is being modified.

PROTOTYPE ENGINE ENDURANCE TEST

A concrete slab has been poured for the endurance test stand. A purchase order has been placed for the fabrication of a hydrogen heater to simulate regeneration.